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MEMORANDUM REPORT NO. 1508
AUGUST 1963

A METHOD OF OBTAINING A MASSIVE HYPERVELOCITY PELLET FROM A SHAPED CHARGE JET

A. Merendino
J. M. Regan
S. Kronman

RDT & E Project No 1M010501A006

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

MEMORANDUM REPORT NO. 1508

AMerendino/JMRegan/SKronman/jk
Aberdeen Proving Ground, Md.
August 1963

A METHOD OF OBTAINING A MASSIVE HYPERVELOCITY PELLET FROM A SHAPED CHARGE JET

ABSTRACT

A method of isolating the tip of a shaped charge jet is described. The tip, thus isolated, provides a massive pellet for research in the field of hypervelocity impact. Aluminum pellets of 3.2 to 4.0 grams mass with velocities between 7.57 and 10.95mm/μsec (25,059 and 35,478 feet per second) were produced with a 3.33-in diameter Composition B charge. For one charge design, in which sufficient observations were made, the standard deviation of the velocity was only 0.10mm/μsec.

Shaped charge scaling laws predict that pellets in the order of hundreds of grams can be ejected at equivalent velocities.

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INTRODUCTION

Researchers in the field of hypervelocity impact need a simple, economical, and reliable device that will provide a compact mass having a velocity greater than 7,000 meters per second. The presence of high-velocity particles within a shaped-charge jet has been known for many years. The studies reported here are an extension of an earlier attempt[1] to isolate leading portions of a jet by inhibiting the collapse of basal portions of the liner. The original experiments were only partially successful because the material used to inhibit the liner collapse did not have appropriate physical properties. Techniques described in this report have been completely successful in isolating the tip of the jet. The isolated tip is identified as an "Inhibited Jet Pellet" to distinguish it from other types of hypervelocity pellets.

CHARGE AND INHIBITOR DESIGN

The shaped-charge design illustrated in Figure 1 was chosen because flash radiographs showed the presence of a large mass of high-velocity materiel at the tip of the jet (Figure 2). The short tube at the apex of the liner appeared to be an essential factor in producing the massive jet tip and was retained for all charge designs tested. To control the degree of liner collapse and allow only the tip of the jet to form, an inhibitor was designed to fit within the liner cavity (Figure 3). The sides were made to conform with the liner angle and the center was removed to permit uninterrupted passage of the jet tip. As the experiments progressed, the height and material of the inhibitor, as well as the apex angle of the liner, were varied.

The tip of the jet was radiographed in flight with a 300-kv flash x-ray unit (Model P. S. -300-1000-0.2) manufactured by the Field Emission Corporation. Two x-ray tubes were arranged to radiate perpendicular to the jet path as shown in Figure 4. Tubes No. 1 and 2 were flashed sequentially with a known time delay between flashes, and the velocity was determined from the distance of travel measured on the radiographs.

A radiograph showing effects produced by a copper inhibitor having a total height of 1.90 inches, in a 45° liner, is presented in Figure 5. A portion of the jet tip and the jet material immediately behind it were eliminated. However, there still existed a considerable amount of high velocity material a short distance behind the tip. The copper inhibitor evidently permitted portions of the liner near the apex to form a jet and pass through the hole in the inhibitor before it closed. To reduce the time for closing the passage through the inhibitor, new inhibitors were made from Lucite which has a lower density (1.18 gm/cc as compared to 8.9 gm/cc for copper) and a reasonably high rate of shock propagation (2.7mm/μsec as compared to 3.5mm/μsec for copper). Results obtained with the first Lucite inhibitor, 1.90" high in a 45° liner, are illustrated in Figure 6. Although only a small portion of the pellet was formed, all the high-velocity jet material immediately behind the pellet was eliminated.

The degree of success in eliminating the high-velocity jet material can be determined from the terminal ballistic effects produced by whatever material emerges from the base of the inhibitor. Discrete pellets, impacting with sufficiently high velocities, produce nearly hemispherical craters in semi-infinite targets. On the other hand, if the material is rod-like in shape or if a stream of high velocity material is produced, the craters become elongated in depth.

The terminal ballistic effects produced in steel targets, by charges having copper and Lucite inhibitors 1.09" high, and 45° apex liners, are illustrated in Figure 7. The sectioned steel targets show clearly that the Lucite inhibitor isolates a single pellet and eliminates the trailing high-velocity jet material; whereas, the copper inhibitor permits a stream of high-velocity particles to impact the target producing a much deeper crater. There still remains, however, some low-velocity material (velocity $<$ [illegible] mm/μsec) which would seriously deform soft target materials such as pure aluminum. Elimination of the low-velocity particles will be described in a later section.

Since the Lucite inhibitors were completely successful in eliminating the extraneous high-velocity material, more Lucite inhibitors 0.50", 1.00", and 1.50" high, in 45° apex liners (Figure 3), were studied. The results are

illustrated by the radiographs shown in Figure 8. The shortest inhibitor did nothing more than create a slight disturbance in the jet, the longest eliminated all of the high velocity jet material and almost all of the pellet; whereas, the one of intermediate height eliminated all of the high-velocity jet material and about half of the pellet. Obviously, changes in height drastically affect the resulting jet formation.

Further experiments with Lucite inhibitors in 37° aluminum liners were conducted. Figure 9 illustrates the features of the undisturbed jet and radiographs in Figure 10 illustrate the degree of isolation of the tip achieved with inhibitors 1.00", 1.06", 1.12", 1.25" and 1.37" high. The extraneous high-velocity material was not present and isolation of the jet tip is obvious.

INHIBITOR AND LINER COLLAPSE STUDIES

The collapse of copper and Lucite inhibitors was studied by radiography. Charges with 45° liners and inhibitors 1.09 inches high were used. To observe the inhibitor during collapse it was necessary to use the 600-kv flash x-ray unit (Model P.S. -600-2000-0.?) manufactured by the Field Emission Corporation to reveal sufficient detail. It should be remembered that the pellets and associated material will appear much less dense in radiographs taken with the 600-kv unit than in similar radiographs taken with the 300-kv units.

The collapse of a copper inhibitor is illustrated in Figure 11. The first radiograph was taken 27 microseconds and the second 37 microseconds after initiation of the charge. For the shorter time delay, with a copper inhibitor, the pellet has already emerged and moved a short distance from the base of the inhibitor. The pellet is immediately followed by aluminum jet material with velocity close to that of the pellet. For the longer time delay the radiograph clearly shows material still emerging from the base of the inhibitor. The collapse of a Lucite inhibitor is illustrated in Figure 12. At 27 microseconds the radiograph of the Lucite inhibited jet shows the pellet at the same location as was observed for the copper inhibitor but the trailing material is trivial in quantity. At 37 microseconds, where the presence of jet material is obvious with a copper inhibitor, there is only a very slight trace of trailing material which has a negligible, if any, effect on the target (Fig. 7).

The mechanism by which the Lucite inhibitor isolates the tip of the jet has been reconstructed using the flash radiographs as a guide. As illustrated in Figure 13, the collapse of the inhibitor is an essential feature in eliminating the high-velocity jet material that would otherwise follow closely behind the pellet. At a much later time, the slug from the liner and the debris from the inhibitor emerge with a velocity less than 1.5mm/μsec.

ELIMINATION OF LOW-VELOCITY MATERIAL

To observe both the pellet and the low-velocity debris from the inhibited shaped charge, the x-ray tubes shown in Figure 4 were pulsed sequentially with the No. 2 tube being pulsed first to radiograph the pellet and the No. 1 tube being pulsed much later ($\sim$ 400 μsec) to radiograph the debris.

Radiographs showing the pellet and low-velocity debris are presented in Figure 14. The distance between the pellet and debris is much greater than that shown in Figure 14 due to the large time delay between the two radiographs.

Two methods of deflecting the low-velocity debris were tried. The first was an explosive stick placed some distance in front of the charge (Figure 15) in an effort to deflect the debris during flight. The second was the addition of a semi-annular section of explosive at the base of the charge (Figure 16) in an effort to deflect the debris immediately following collapse. The results are illustrated by the radiographs presented in Figures 17 and 18.

Since both x-ray tubes view the event from the same direction, the angle of deflection can be measured from the radiographs using the point of deflection and the direction of travel of the pellet as a reference. To facilitate measurement of the deflection angle, the charges were oriented in such a way that the debris would be deflected in a plane perpendicular to the radiation.

The explosive stick provides an angle of deflection (Figure 17) such that the unwanted material can be trapped by a baffle plate. However, the explosive stick complicates the experimental arrangement because two charges must be precisely aligned and detonated with the proper time delay.

The semi-annular section of explosive at the base of the charge provides adequate deflection of the low-velocity material (Figure 18) without damaging the high-velocity pellet. Once again, the debris can be trapped by a baffle plate. Because the additional section of explosive can be rigidly attached to the principle charge, difficulties in using the assembly are minimized.

EFFECT OF LINER APEX ANGLE ON PELLET VELOCITY AND MASS

The velocity of the tip of a shaped-charge jet increases monotonically with decreasing liner apex angle with the velocity approaching a theoretical value equal to twice the detonation rate for jet tips produced by cylindrical liners (0° apex angle)[2]. The jet tip velocity was determined for liners having apex angles of 20°, 25°, 30°, 37°, 45° and 60°. The charge length (Figure 1) was modified for each apex angle to maintain a constant distance of 1-1/4 inches between the top of the liner and the tetryl booster. The measured velocities are presented in the table below.

TABLE I

Liner Apex Angle	20°	25°	30°	37°		45°	60°
Jet Tip Velocity	11.70	10.98	10.39	-	9.59	8.86	7.57
(mm/μsec)		10.91		9.50	9.64		
				9.53	9.66		
				9.56	9.72		
				9.58	9.75		
				9.59	9.80		
				9.59	9.81		
Average	11.70	10.95	10.39	9.64		8.86	7.57
STD DEV.				0.10			

The velocity of the jet tip is shown as a function of the liner apex angle in Figure 19. The velocity of 15.6 mm/μsec at the intercept is the theoretical value for twice the detonation rate of Composition B (7.8 mm/μsec).

The radiographs of the jet tips for the liner apex angles shown in Table I indicate that useable pellets are produced with angles from 25° to 60° (the largest angle investigated). The 20° apex angle liner did not produce a consolidated pellet at the jet tip and at present its usefulness is doubtful.

However, more experiments should indicate the proper design modification necessary to make this jet tip coherent also. Radiographs of the jet tips produced by liners with 30°, 37°, 45° and 60° angles are shown in Figure 20.

For hypervelocity impact studies the mass of the pellet must be determined by an independent observation. If the pellets are solid aluminum, the mass can be determined by measuring the pellet size from a radiograph. Pellet solidity was checked by a simultaneous radiograph (Figure 21) of a pellet and a solid aluminum rod, approximately equal in diameter to the maximum diameter of the pellet. A comparison of the intensities shows that there is no appreciable difference in density between the pellet and rod. Estimates of mass were made for the pellets shown in Figure 20 along with estimates for two pellets produced by an inhibited (1.25 inches high) 37° apex liner. The results are tabulated below.

TABLE II

	UNINHIBITED				INHIBITED
LINER APEX	30°	37°	45°	60°	37°
ESTIMATED MASS	3.3	4.0	3.2	3.6	3.4
(GRAMS)					3.6

SUMMARY

A technique has been developed for producing aluminum pellets having velocities between 7.57 and 10.95 mm/μsec. Jet tip velocities up to 11.7 mm/μsec have been achieved; however, some design modifications may be required to achieve a concentration of liner mass at the tip of the jet. A pellet mass of 3.2 to 4.0 grams is readily obtained using a liner having a 3.33-inch base diameter. Because shaped charges follow a linear scaling relation[2], it appears that the mass of the pellet can be increased, for

example, to about 200 grams by increasing the charge diameter to 12 inches. Thus, by changing the apex angle and charge size, the pellet velocity and mass can be varied over a sufficient range to provide a simple, economical, and reliable device for obtaining terminal ballistic data to study hypervelocity impact phenomena.

ACKNOWLEDGMENTS

The authors are grateful to Dr. F. E. Allison for his assistance in the preparation of this report. We also wish to express our thanks to Messrs. B. Taylor and R. McNall for the excellent radiographs they provided.

A. MERENDINO

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2. Birkhoff, Garrett, MacDougall, Duncan P., Pugh, Emerson M., and Taylor, Sir Geoffrey. Explosives with Lined Cavities. Journal of Applied Physics, Vol. 19, No. 6, Page 563-582, June 1948.

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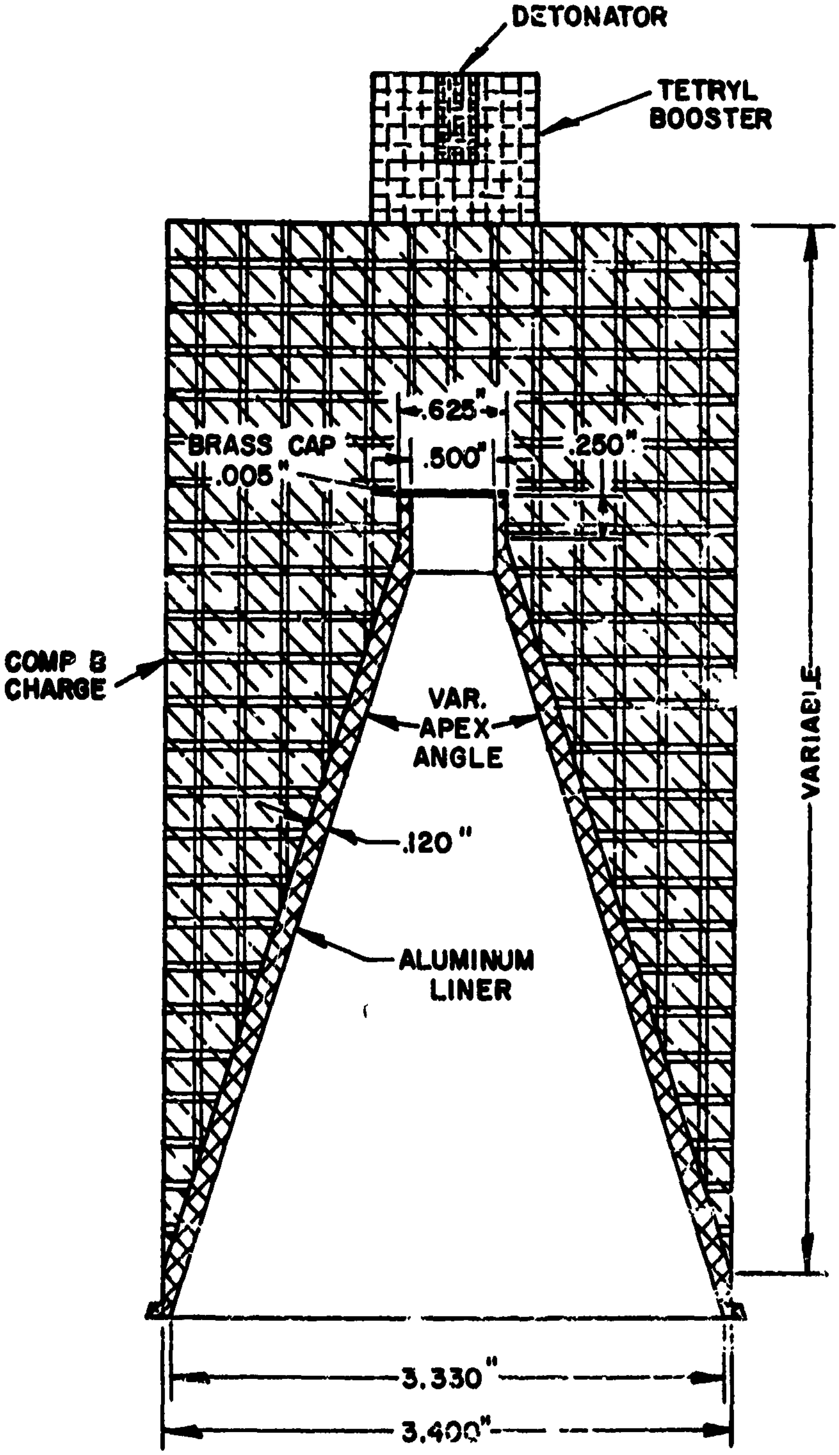
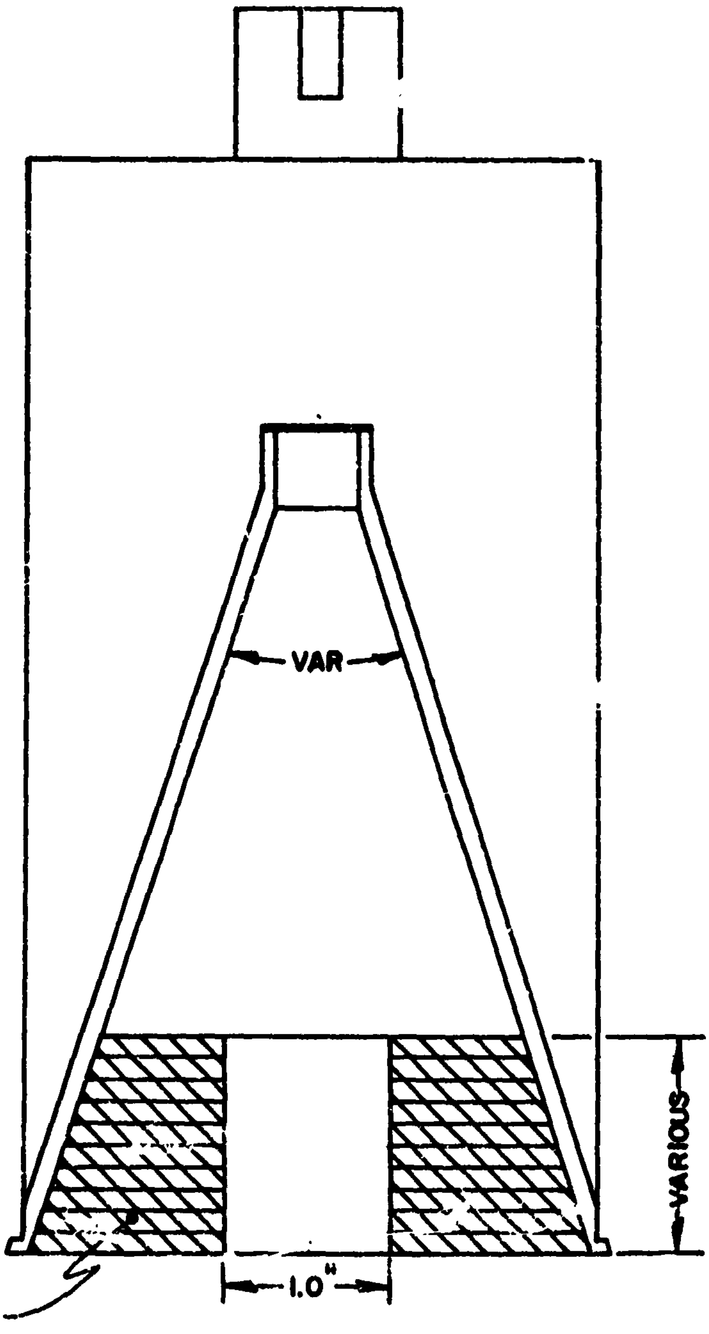


Figure 1 Design of shaped charge used in all experiments.

Figure 2 Radiograph of the leading portions of the jet from the shaped charge design illustrated in Figure 1. Note the massive portion at the jet tip.



NOTE: FOR DETAILS NOT SHOWN, REFER TO FIGURE 1.

Figure 3 Location of inhibitor within charge illustrated in Figure 1.

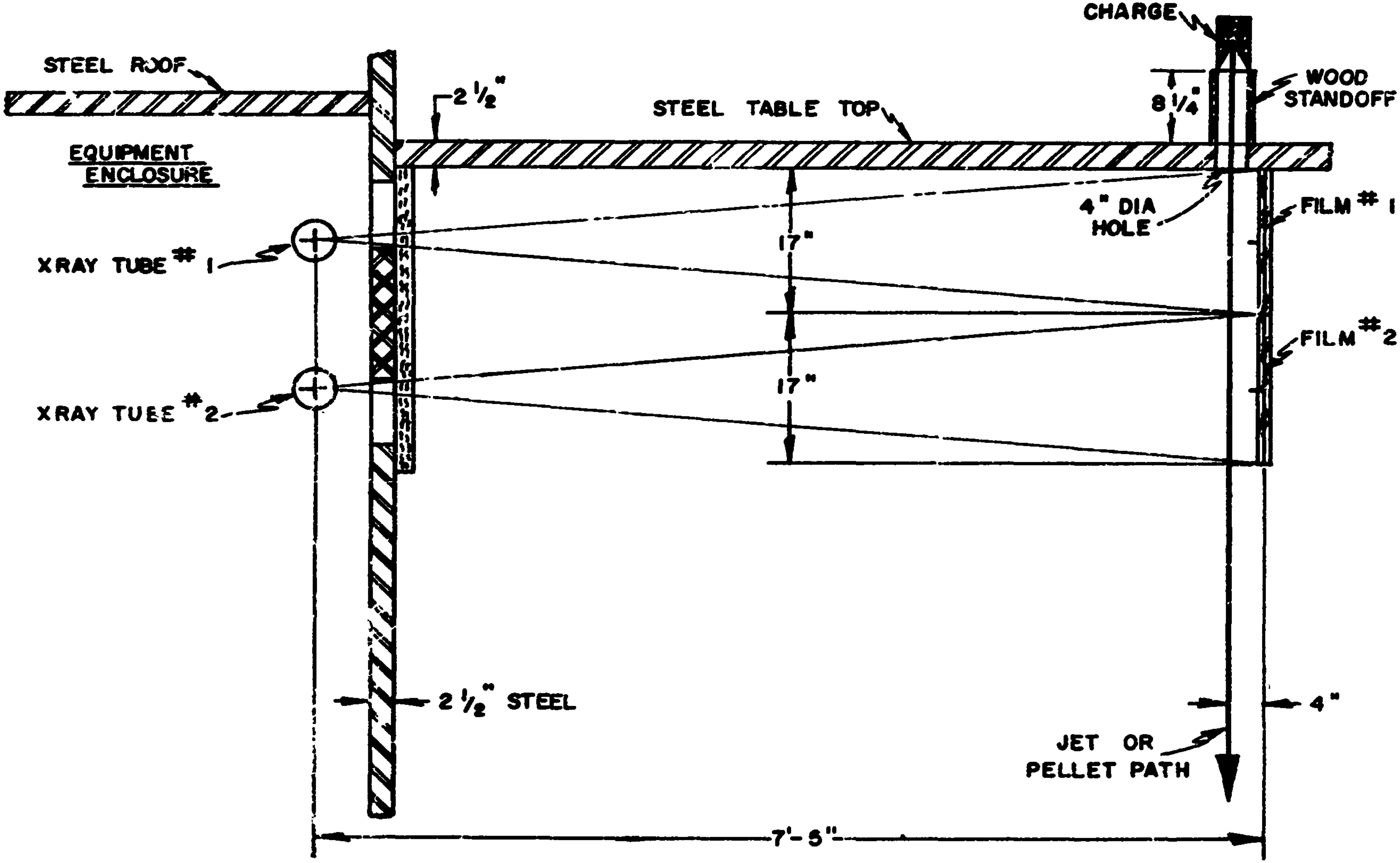


Figure 4 Schematic of the test site used for radiography of the jets.

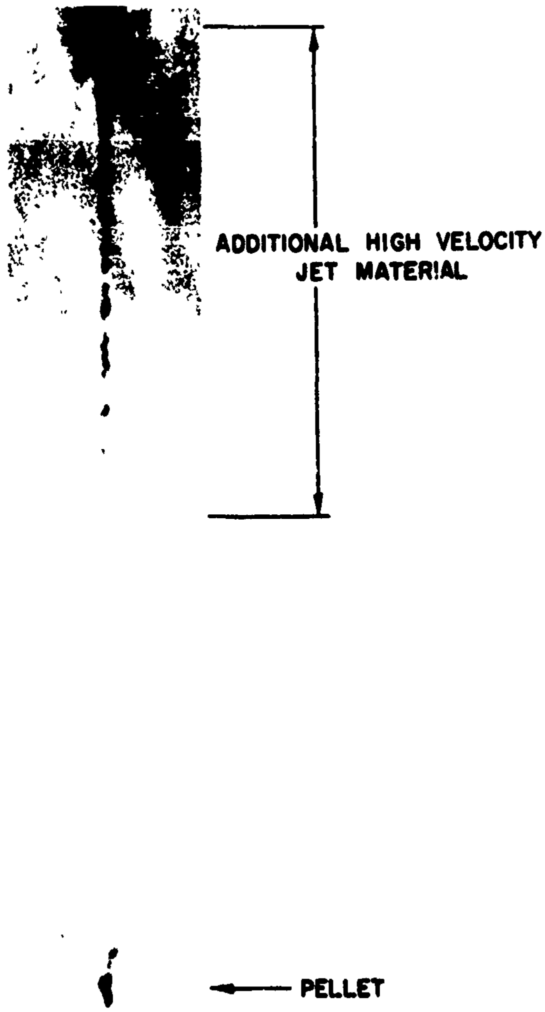
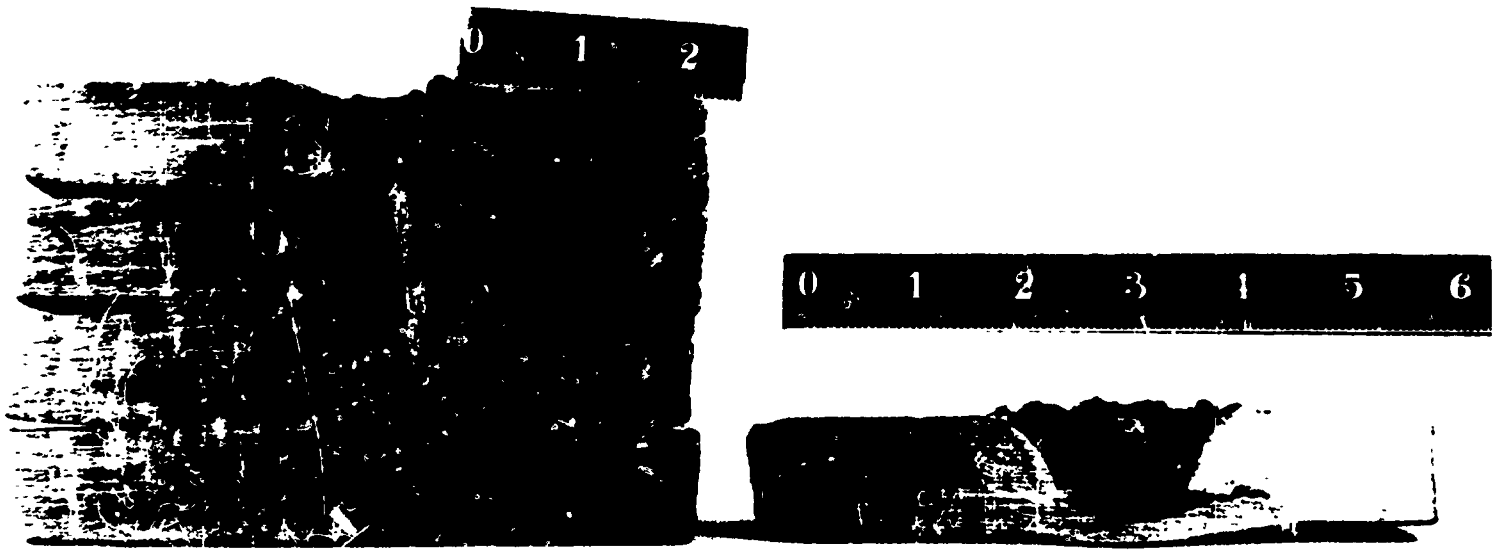


Figure 5 Jet from a charge with a 45° liner and a 1.90" high copper inhibitor.

9

Figure 6 Jet from a charge with a 45° liner and a 1.90" high Lucite inhibitor. Note the absence of high velocity jet material behind the pellet.

0 50 100 MM



A B

Figure 7 A comparison of the terminal effects on mild steel target by jets from charges with (A) Copper and (B) Lucite inhibitors. Inhibitor height was 1.09" and the liner angle was 45°.

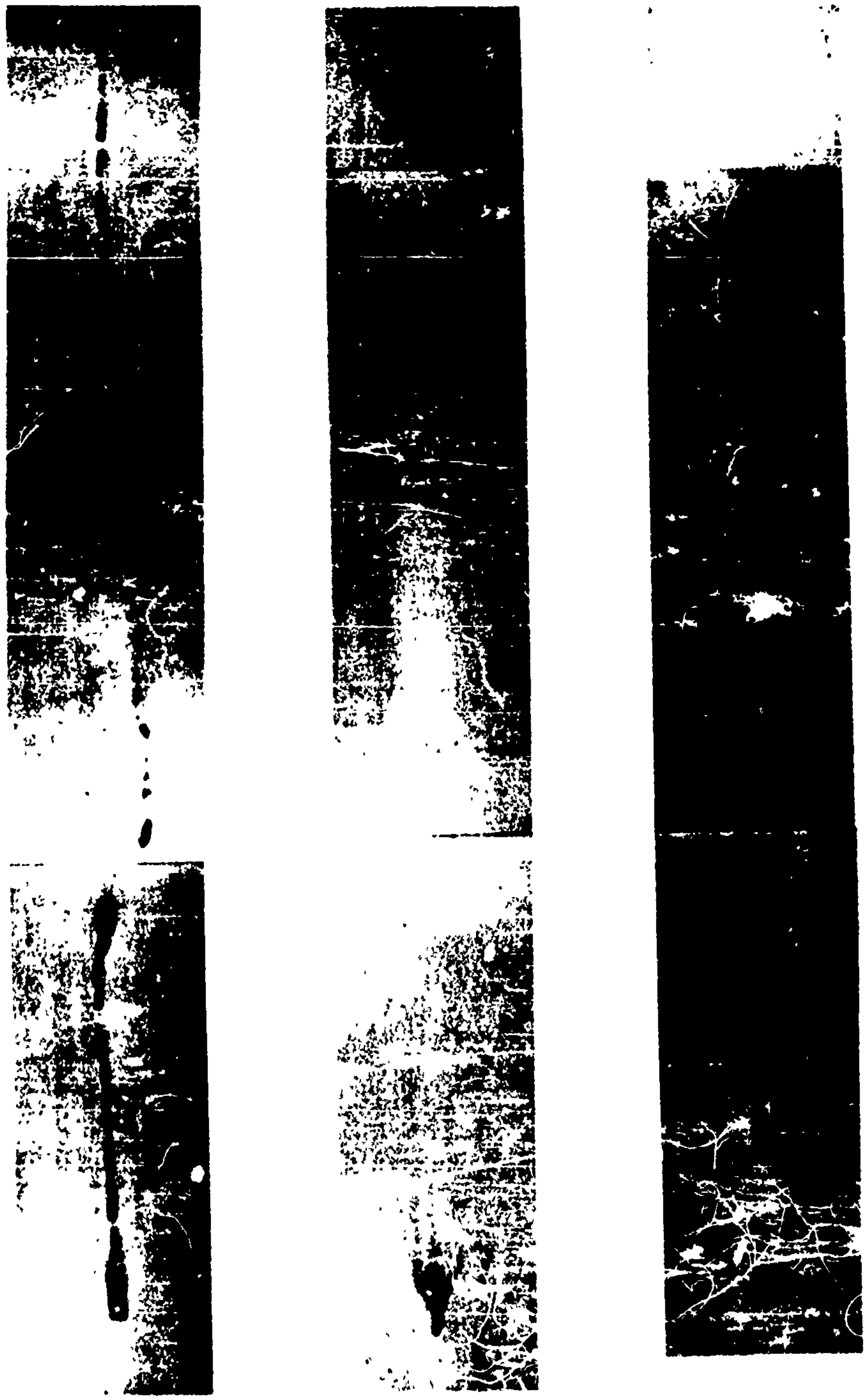


Figure 8 Radiographs of the leading portions of jets from charges with Lucite inhibitors (left to right) 0.50, 1.00 and 1.50 inches high.

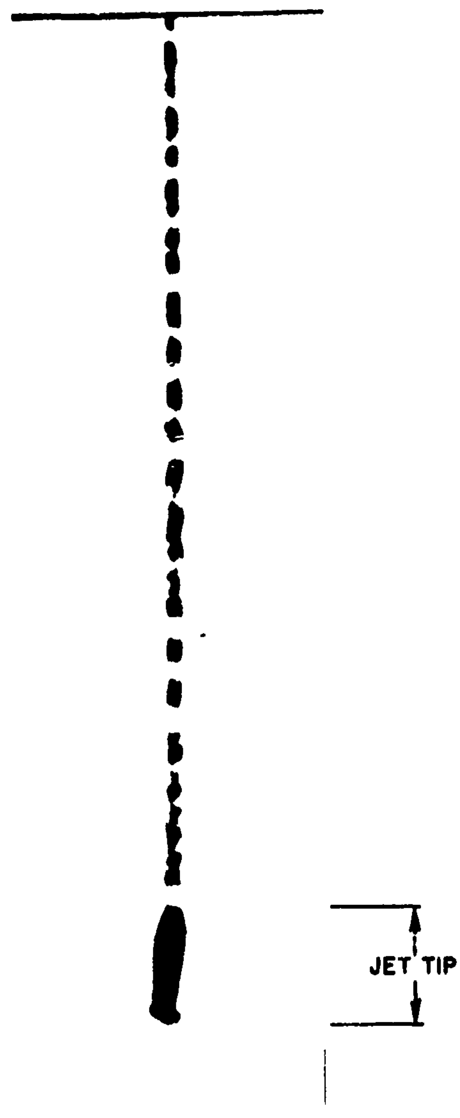
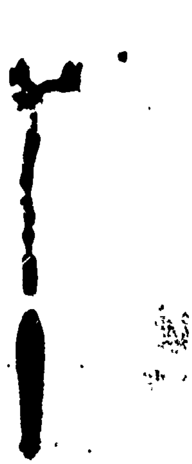


Figure 9 Radiograph of the leading portions of the jet from an uninhibited charge with a 37 degree apex liner.



INHIBITOR HEIGHT - 1.00 "

INHIBITOR HEIGHT - 1.06 "

INHIBITOR HEIGHT - 1.12 "

INHIBITOR HEIGHT - 1.25 "

INHIBITOR HEIGHT - 1.37 "

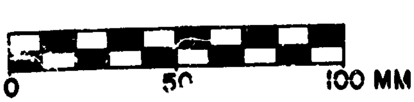


Figure 10 Radiographs of jet tips with various degrees of isolation by Lucite inhibitors of the heights indicated.

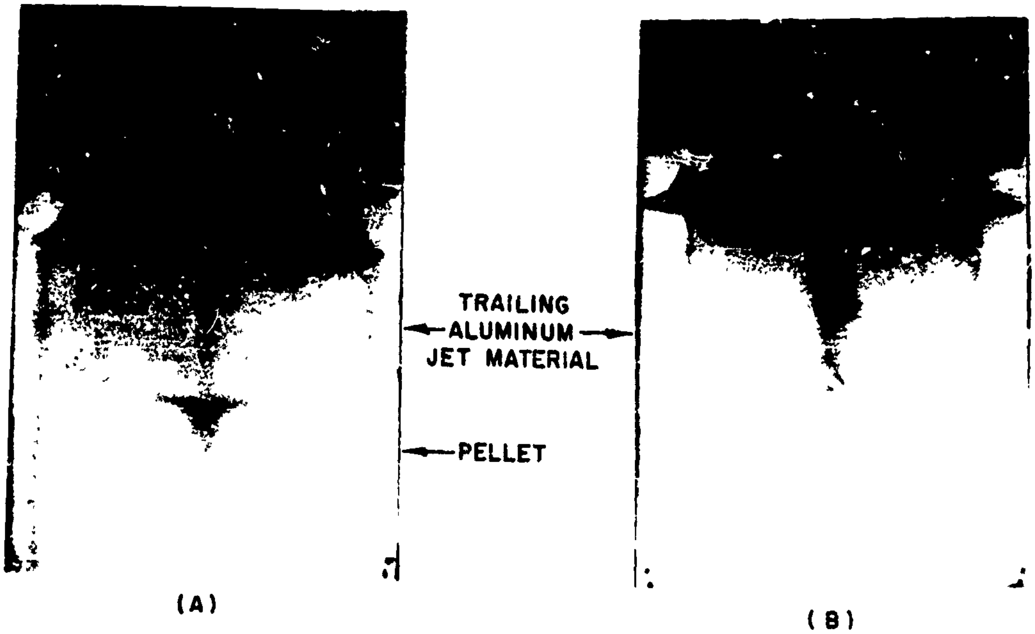


Figure 11 Radiographs of charges, with Copper inhibitors, showing the liners at intermediate stages of collapse, (A) at 27 microseconds and (B) at 37 microseconds after charge initiation.

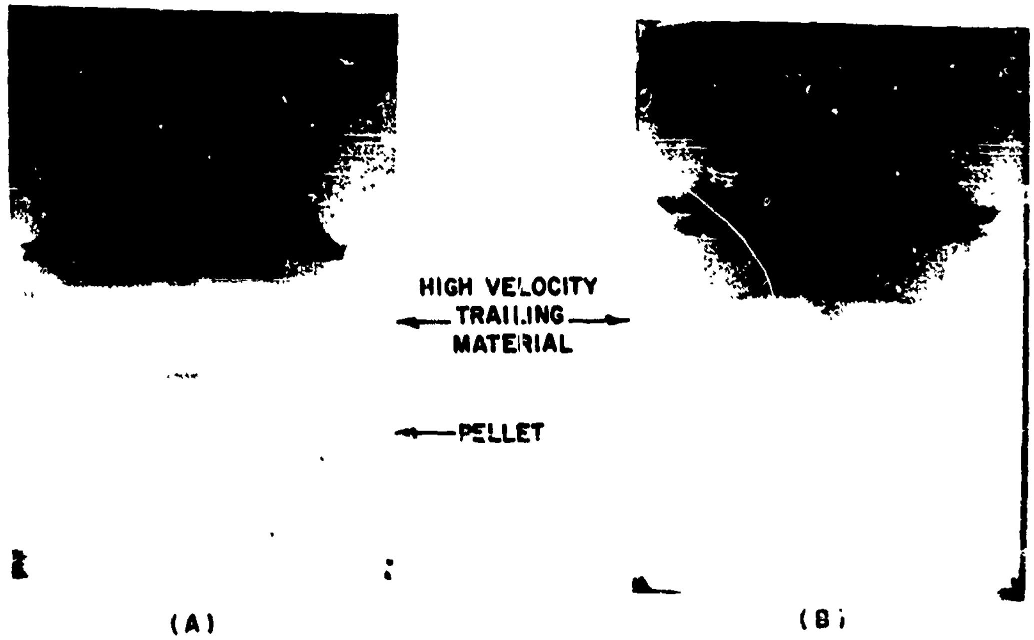


Figure 12 Radiographs of charges, with Lucite inhibitors, showing the liners at intermediate stages of collapse, (A) at 27 microseconds and (B) at 37 microseconds after charge initiation.

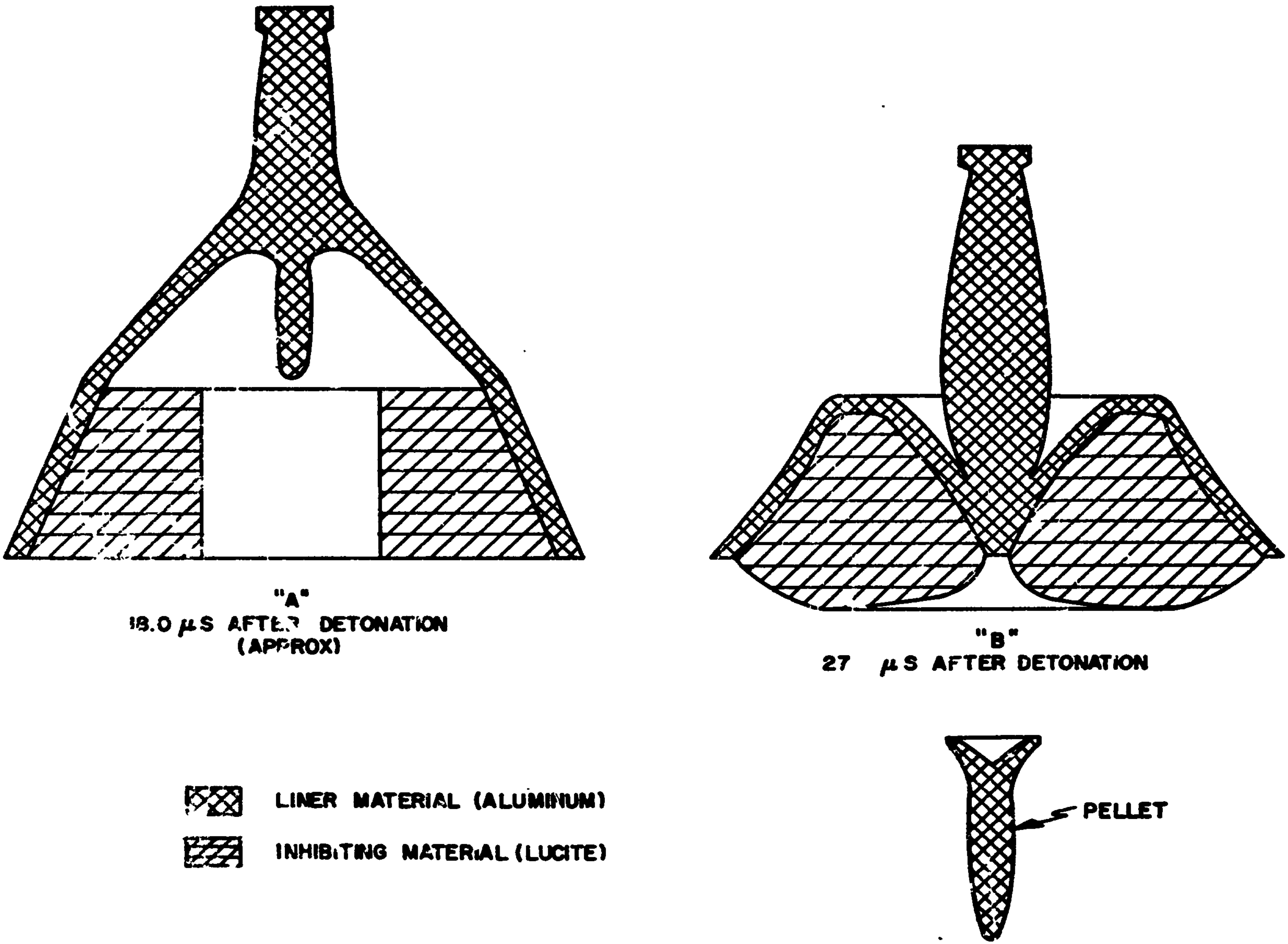


Figure 13 Illustration of liner collapse and effect of inhibitor based on detailed examination of radiographs.

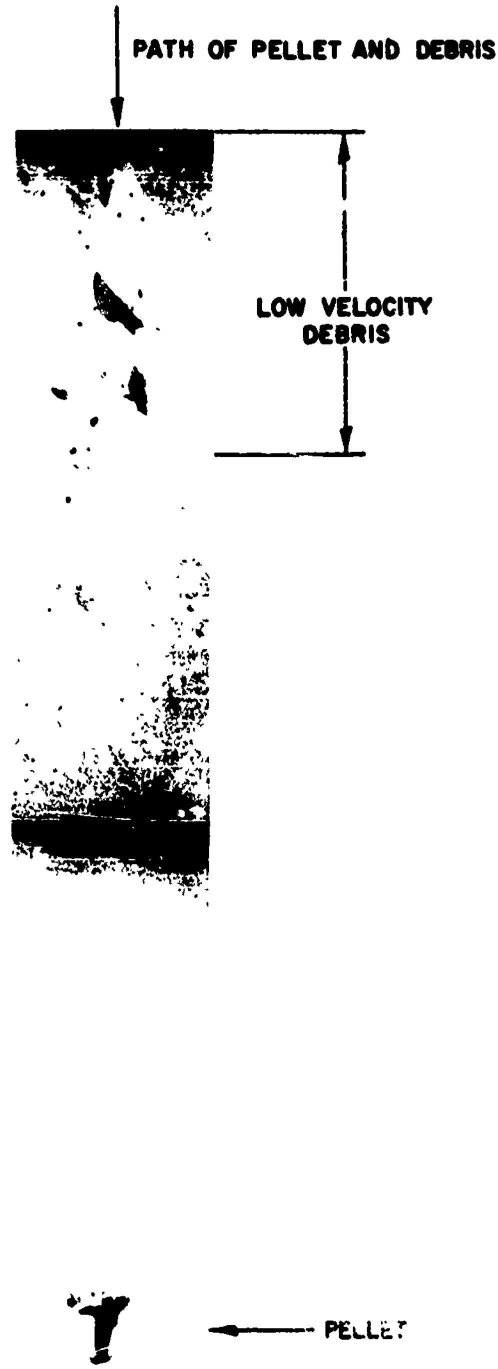


Figure 14 Radiograph of an isolated pellet together with the low-velocity debris following in line but far behind.

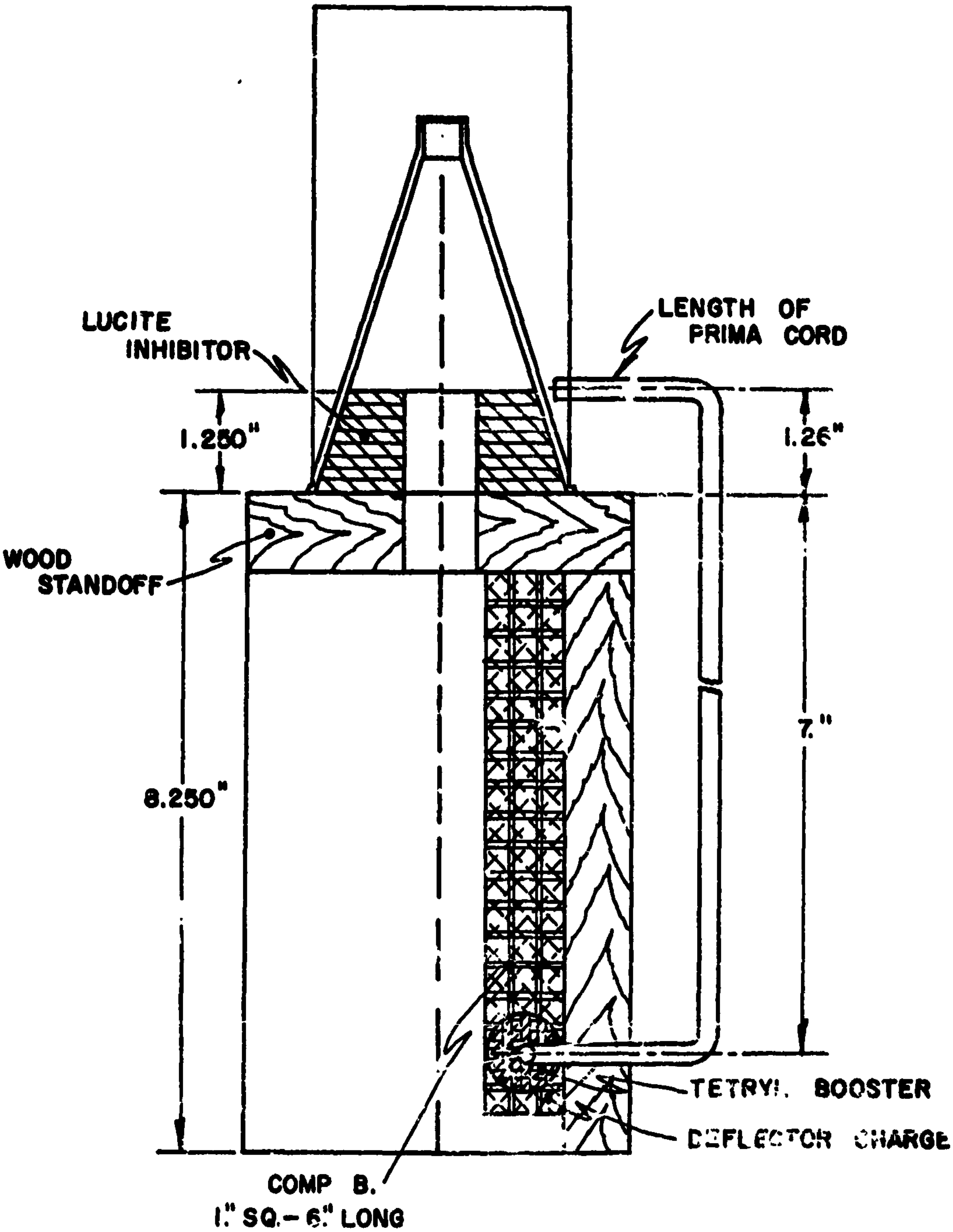


Figure 15 The addition of an explosive stick near the pellet path to act as a deflector device.

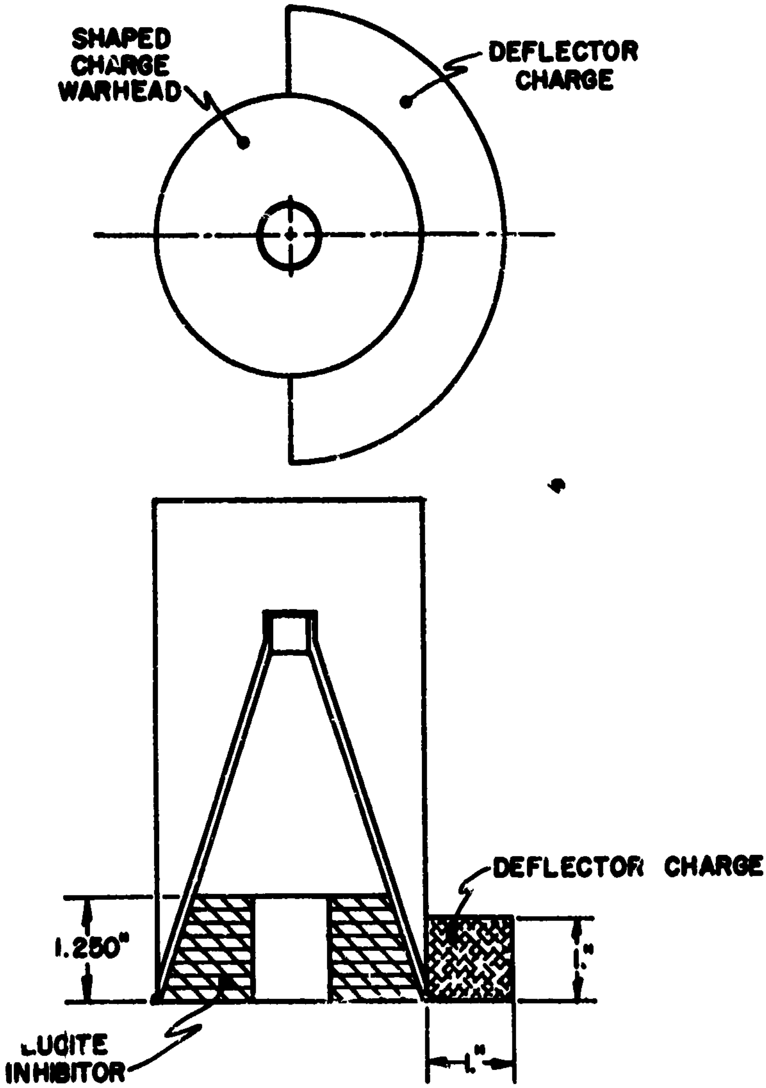


Figure 16 The addition of a semi-annular explosive belt at the base of the charge to act as a deflector device.

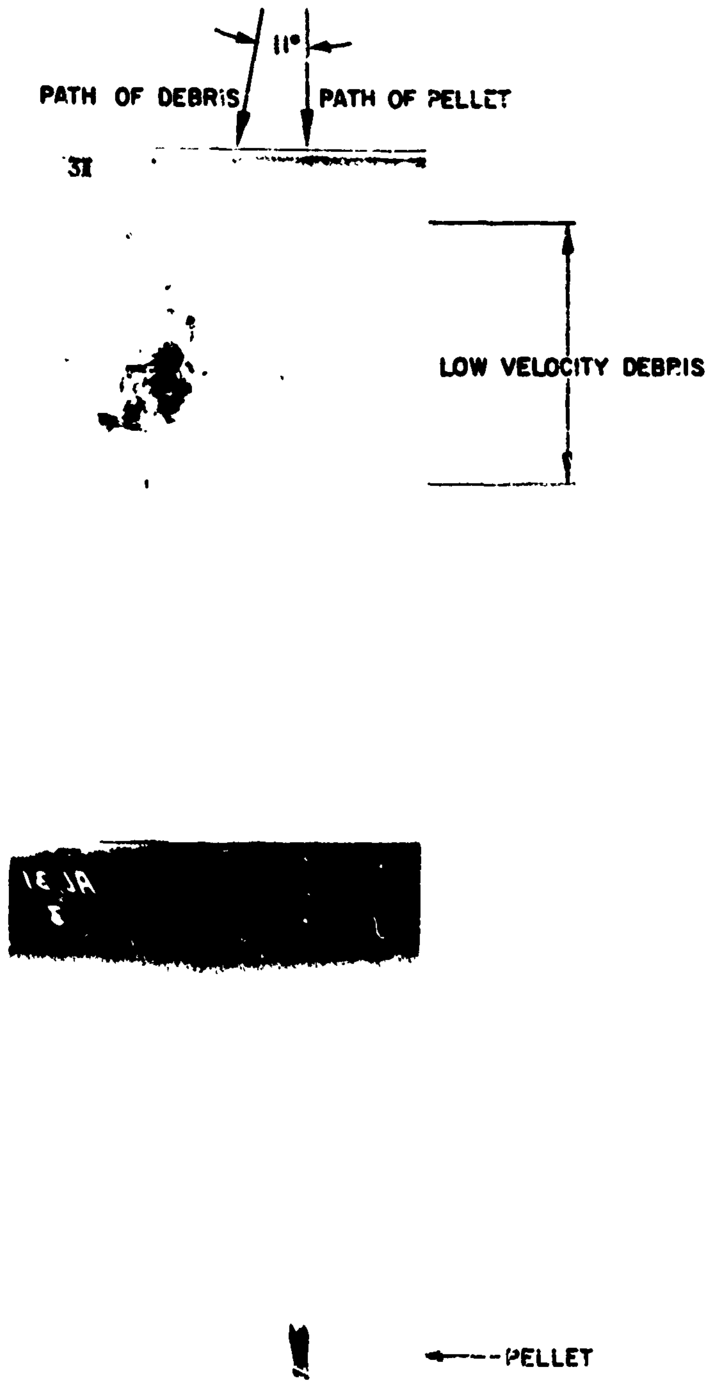


Figure 17 Radiograph of a pellet, and low-velocity debris, from the charge illustrated in Figure 15. The debris is deflected at the angle indicated.

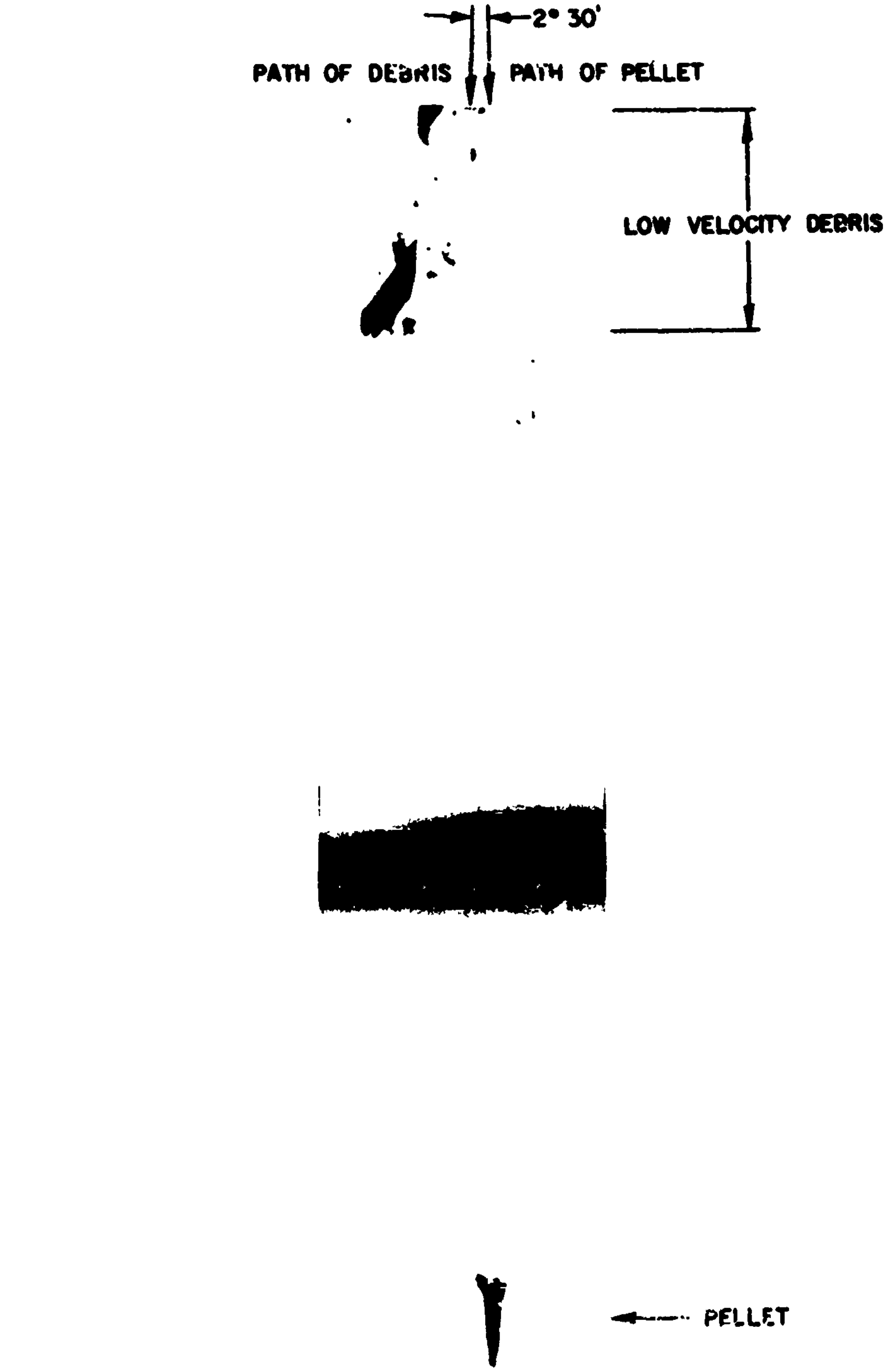


Figure 18 Radiograph of a pellet, and low-velocity debris, from the charge illustrated in Figure 16. The debris is deflected at the angle indicated.

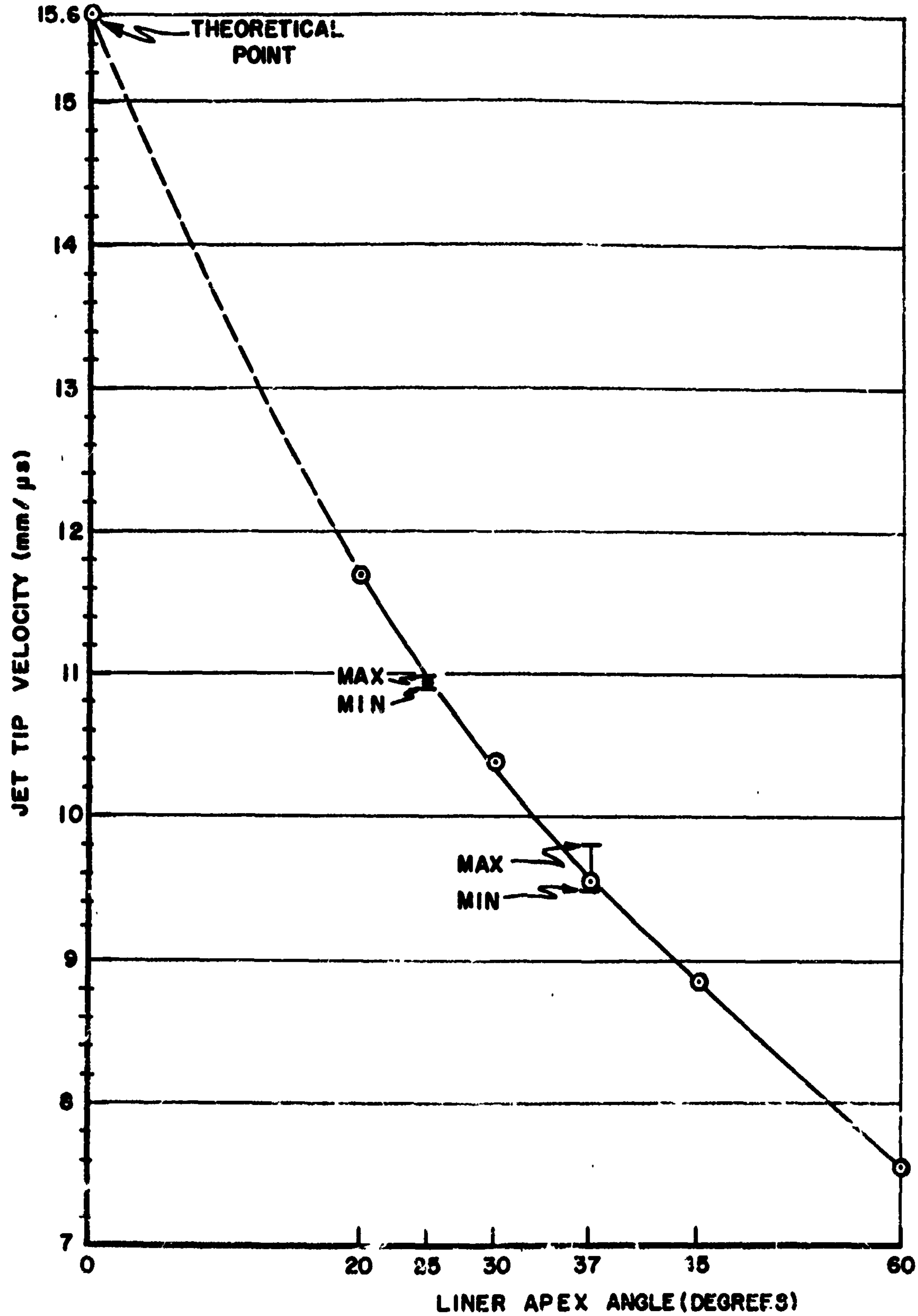


Figure 12 Effect of the liner apex angle on the jet tip velocity.

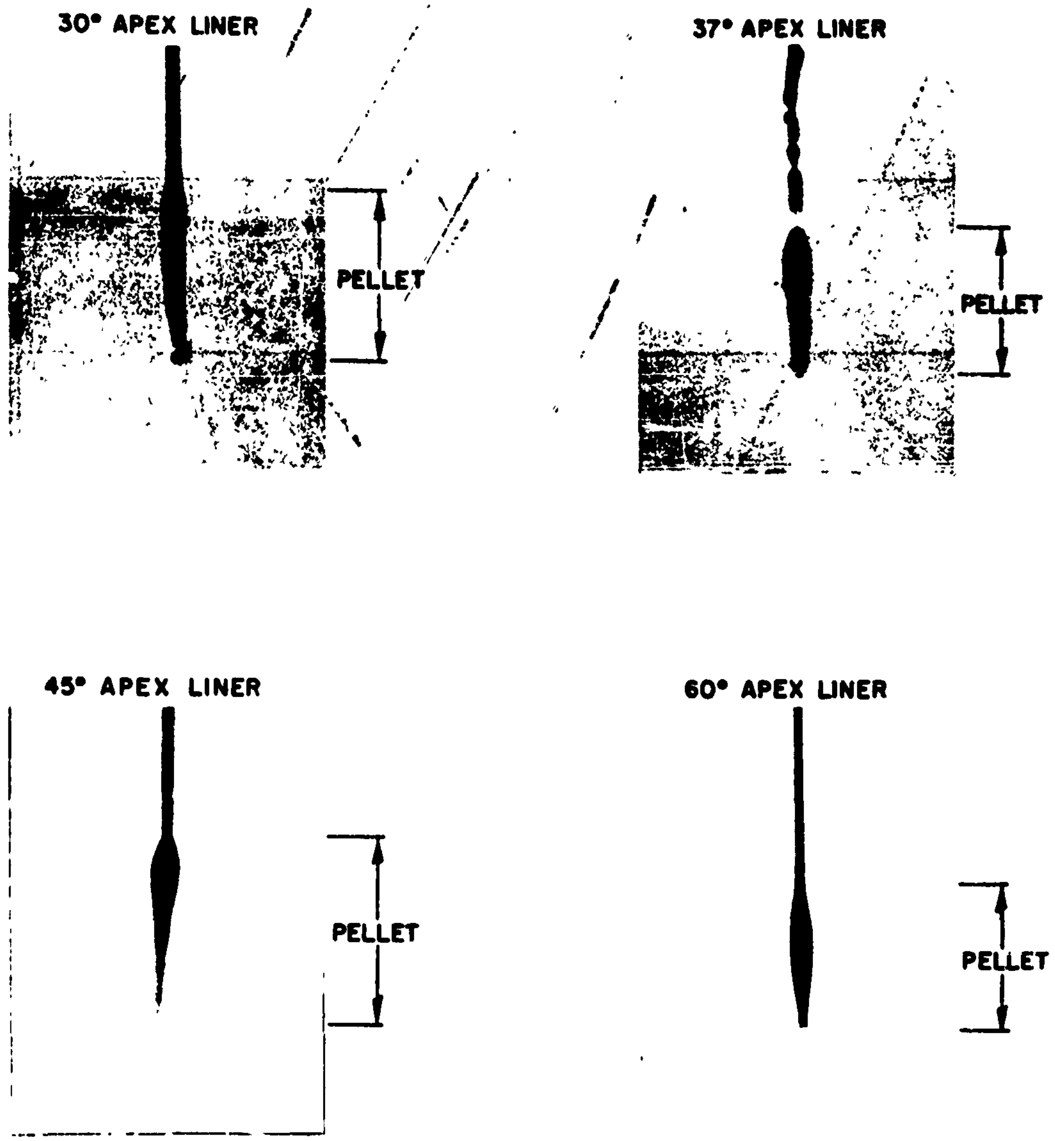


Figure 20 Radiographs of pellets produced by liners with apex angles as indicated.

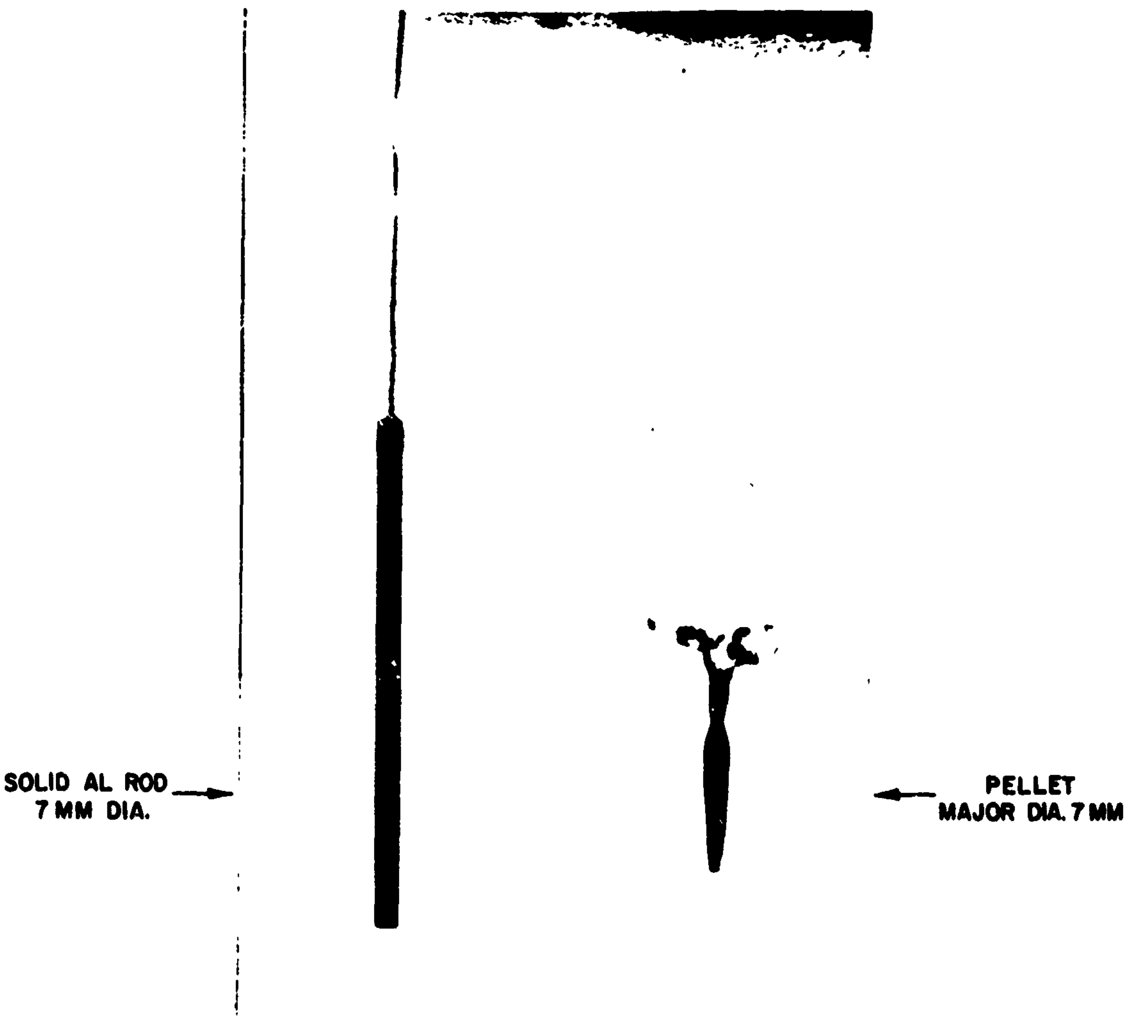


Figure 21 Simultaneous radiograph of a pellet and a solid aluminum rod of the same diameter to demonstrate the solidity of the pellet.

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A. Merendino, J. M. Regan and S. Kronman

Hypervelocity impact
Shaped charge jets
Jet pellets

BRL Memorandum Report No. 1508 August 1963

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Shaped charge scaling laws predict that pellets in the order of hundreds of grams can be ejected at equivalent velocities.

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